A STUDY IN CONSANGUINITY OF ERUPTIVE ROCKS.

WITHOUT being distinctly formulated, the principle of consanguinity recently enunciated by Prof. Iddings has, as a working hypothesis, been the guide of studies made within the last few years on a group of Brazilian eruptive rocks, and the means of arriving at some interesting and, in part, novel results. The method of study followed, partly by plan, partly from force of circumstances, being the comparative study of a group of localities on the assumption of genetic relations between them, rather than detailed work at single points, was similar to what would be applied to the study of a sedimentary group. This method has in this case proved of great advantage, and, as a contribution to the subject of consanguinity, seems worthy of being put on record.

In 1883, the writer, whose previous training had been almost exclusively in the domains of palæontology and the distinctly sedimentary formations, finding himself in a region of crystalline and metamorphic rocks felt the need of acquainting himself with modern petrographic methods. Working in complete isolation without previous instruction in this branch, without material for comparison and almost without literature, he was also without the traditions of the science and preconceived ideas of the relations of the different petrographic groups, and thus free to follow out the lines of investigation suggested by their apparent field relations.

In working over the material at hand in the National Museum at Rio, attention was attracted to specimens of nepheline-syenite, or foyaite (using that term as a general title for the holocrystalline nepheline-orthoclase rocks) and as one of the localities, the peak of Tingua, was readily accessible from Rio an attempt to determine its field relations was resolved upon. This heavily wooded mountain proved a hard nut to crack, and several excursions gave very slender results beyond the fact that

with the predominant foyaite, phonolite and basaltic rocks, which have since been named monchiquites by Prof. Rosenbusch, occurred. These two last types, found only in loose blocks or in small dykes in gneiss that was clearly older than the foyaite, gave no idea of their relations to the latter rock except that at one point a small dyke of phonolite containing polyhedral inclusions of foyaite, like raisins in a pudding, was observed cutting foyaite of the same type as the inclusions. An examination of a series of railroad cuttings between the peak and the city showed a plexus of phonolite and monchiquite dykes together with a peculiar feldspathic rock of syenitic aspect, which, as they did not extend to the city, were suggestive of a possible genetic connection with the eruptive center of Tingua, or of some other similar center in the vicinity.

The occurrence of phonolites, hitherto only known on Brazilian soil on the volcanic island of Fernando de Noronha, suggested a search for phonolitic centers of eruption. About this time a chance collection made by a naval officer from the island of Cabo Frio, 60 miles from Rio, came to hand. As it contained specimens of both phonolite and foyaite, an excursion was resolved upon, guided by the thought that a rocky island on an open coast should give good exposures and thus perhaps prove a better point than Tingua for the study of the problems presented in this mountain. The island, from two to three miles long and from one-fourth to one-half mile wide, was found to give an almost continuous rock exposure about its entire margin. About four-fifths of the island is composed of coarse grained sodalite-bearing foyaite somewhat different from the Tingua type, and like it cut by numerous dykes of phonolite. The remainder consists of augite-syenite of two types, except a small point which is distinctly tuffaceous and cut by innumerable small dykes of a basaltic character. In one place dyke-like masses and large boulder-like inclusions of a pyroxene-plagioclase rock of a gabbro type occur. The coast of the mainland, distant half a mile more or less from the island, is entirely free from rocks of a syenitic character, and is composed of gneiss cut

by numerous dykes of phonolite, monchiquite and augite-syenite porphyry, as well as of diabase which, as it occurs everywhere in the gneiss regions of Brazil, was not taken into account. Although nothing definite on the field relations of these various rocks could be made out, the idea suggested at Tingua of a possible genetic relation between foyaite, phonolite and monchiquite was strengthened by this repetition of the association and mode of occurrence, that is to say, of a central mass of foyaite with apophyses of phonolite and monchiquite. Aside from this, the association of foyaite with augite-syenite, with a plagioclase rock and with tuff of a volcanic character, suggested other lines of investigation not in accord with the usually received notions regarding these rocks.

Before a second projected excursion to Cabo Frio could be realized a chance specimen of foyaite from the Poços de Caldas in southern Minas appeared at the Rio Museum. As a railroad was under construction in this region the idea at once presented itself that, aside from a study of this district, possibly Tingua and Cabo Frio might be studied more advantageously several hundred miles away than at those points themselves. Instead, therefore, of returning to Cabo Frio an excursion was made to Poços de Caldas where the expectations formed were more than realized. About twelve kilometers of almost continuous rock cutting up a steep mountain slope giving one of the finest and most varied exposures of eruptive rocks in the world, was found. Here immense masses of tuff are seen to be cut by both foyaite and phonolite ; dykes and sheets of foyaite pass into phonolite at their margins ; small masses of phonolite[1] are seen included in foyaite and *vice versa* masses of foyaite are included in phonolite. Considerable masses of a leucite rock, the first known from South America, cut by and buried under phonolite and presenting tuffaceous facies also occur. Small stringers of augite-syenite were noted in the tuffs and phonolite, and nests of

[1] The name phonolite is retained for these rocks since no petrographer, not knowing their association, would ever think of calling them anything else, although some, with that knowledge, prefer to call them nepheline-syenite porphyries or tinguaites.

decomposed crystals, at first taken for analcime, as well as polyhedral inclusions similar to those of the phonolite of Tingua were obtained. To complete the felicity of the excursion a cutting at the foot of the mountain showed the eruptive rocks to be in part, at least, contemporaneous with Carboniferous strata.

With the data here obtained a paper was prepared and presented to the Geological Society of London (Quart. Jour. 43; 1887) announcing the discovery and general distribution of nepheline and leucite rocks in Brazil, and the general conclusion that the Poços de Caldas eruptive center is volcanic in the most restricted sense of the term, that it is of Carboniferous age, and that here foyaite and phonolite occur as different phases of the same magma.[1]

The attack on Tingua was now renewed with the expectation that a diligent search would reveal something analogous to the Caldas region. A trip to the top of the peak showed little of interest beyond a dyke of phonolite cutting foyaite at the very summit. An examination of the margins, well shown by the cuttings of an extensive series of railroad and pipe lines (for the water supply of Rio) at the front, a river valley at the back and roads over the ridge at both ends of the peak, showed that the foyaite is limited to the massif and nowhere presents unequivocally the character of dykes. Two cuttings, one a tunnel, through a spur covered with foyaite boulders as if from the outcropping of a dyke, is conclusive on this point, as only gneiss was found *in situ*. The eruptive rocks are therefore placed like a plaster on the top and slopes of a gneiss ridge in a manner exceedingly suggestive of volcanic conditions. By forcing a way through the dense forest into the crater-like valley of a stream coming from the very heart of the mountain, the long-sought-for evidence of fragmental eruptives and of extensive masses of phonolite in

[1] Subsequent explorations of the Caldas center proves it to be one of the grandest volcanic masses of nepheline rocks known, measuring from fifteen to twenty miles in diameter. Contrary to the first impression the foyaite masses are comparatively insignificant, and the massif is composed essentially of phonolite and tuff with possibly a large proportion of basic leucite rock. A large and important mass of augite-syenite appears to form part of the same volcanic massif.

sheets rather than dykes was found. A complete analogy, as regards the essentially volcanic character of the massif, with the Caldas region was thus established with the addition of evidence of a lava-flow-like character in the foyaite masses. (Quart. Jour. XLVII., 1891).

A chance fracture of a Caldas specimen showing obscurely an appearance of dodecahedral faces on the external surface of the singular polyhedral inclusions so characteristic of the two places, suggested the search for partially decomposed material which by cleaving around the inclusions would show their true form and reveal the mystery of their origin. This search was rewarded with the discovery of free masses of foyaite, like those of Magnet Cove, Ark., having the external form of leucite. The presence of such rock masses with crystalline outlines in both phonolite and foyaite is another link in the chain of evidence of consanguinity of foyaite, phonolite and leucite rocks, while the presence of accessory plagioclase in some of these masses, taken in connection with the occurrence already noted at Cabro Frio, suggests another interesting line of investigation.

Meanwhile another series of studies presented in an unexpected manner certain new and interesting phases of the problem. Work had been commenced on a deposit of magnetic iron ore at Ipanema in the state of São Paulo where, from the extreme decomposition of the rocks and other unfavorable circumstances, but little could at first be made out beyond the association of the ore with a peculiar clay made up in large part of scales of hydrous mica. An ore of similar character at Jacupiranga in the same state was being investigated by Mr. Henry Bauer, a German mining engineer, and the collections sent by him showed the presence at that place of an undescribed type of holocrystalline nepheline-pyroxene rock since denominated jacupirangite,[1] which, by enrichment in iron, passes to an iron ore, and, by secondary alteration of the pyroxene, affords the same peculiar micaceous clay. Certain basic

[1] Am. Jour. of Science, XLI., 1891, p. 311. The same, or a very similar, type was described simultaneously from Finland by Ramsay and Berghell with the name of ijolith (Geologiska Föreningens i Stockholm Förhandlingar, No. 137, 1891).

eruptives in these collections suggested a comparison with the Tingua and Cabo Frio monchiquites, and Mr. Bauer was requested to search for the characteristic rocks of these places, specimens being sent him for comparison. The return mail brought typical specimens of foyaite, and with this indication of a new locality for that rock, and in the hope of being able to study the Ipanema ore deposit more advantageously at another place, an excursion to Jacupiranga was resolved upon. Under the guidance of Mr. Bauer, and aided by subsequent investigations by him and Dr. Eugen Hussak, the district was found to consist essentially of jacupirangite cut by dykes of foyaite with which is associated phonolite, various types of augite-syenite and a micaceous pyroxene-plagioclase rock in such a way that there is no escaping the conclusion of a genetic relation between these various types. Outlying dykes of the plagioclase rock assume in one place the characters of a gabbro, in another, those of a teschenite. Among the outlying dykes of the district are various types of basic eruptives, including leucite-basanite, vosgesite and syenite-porphyry whose relations to the eruptive center are less clear, but which are also suspected to be genetically connected with the nepheline-bearing types. Most interesting is a cryptocrystalline orthoclase-pyroxene rock passing to coarse grained augite-syenite and presenting a tuffaceous facies clearly indicative of volcanic action.

With the clues obtained at Jacupiranga the study of Ipanema became comparatively easy. The jacupirangite type passing to an iron ore was found as a dyke with the facies of a breccia at the margin, traversing decomposed rock which is evidently identical with the compact augite-syenite of Jacupiranga. By diligent search the latter was found in a sound condition and presenting a variety of interesting phases, such as a passage to coarse grained augite-syenite, tuffs identical with those of Jacupiranga and, most interesting of all, a basic facies in which the orthoclase is replaced by phosphate of lime in the form of apatite. A singular mode of occurrence, and one bearing directly on the question of consanguinity, is that of micro and macroscopic inclusions,

or segregations, of both the feldspathic and phosphatic types of augite-syenite in a phonolitic nephelinite, apparently without feldspar. The bulk of the iron ore at this place occurs as rounded nodular segregations associated with apatite in a decomposed rock which was evidently coarse grained and micaceous. This was evidently not jacupirangite, but apparently some peculiar type of nepheline or augite-syenite. Except for the absence of black garnets it apparently corresponds closely with the ore-bearing rock of Magnet Cove, Ark., described by the late Dr. J. F. Williams. It may be noted in this connection that the same character (absence of black garnet) distinguishes the jacupirangite from the ijolith of Ramsay and Berghell.

As in the Caldas region, there is at Ipanema evidence that the eruptive action took place in the late Carboniferous or post-Carboniferous times. This coincidence of age at two of the localities may perhaps justify the assumption (which cannot be directly proven for lack at the other places of sedimentaries intermediate between the very ancient and the very modern), that all of these eruptive centers are substantially contemporaneous. Bearing on this question of age, as also on that of consanguinity, is the fact that in a region characterized by Devonian and probably also Carboniferous strata in Paraguay, Pohlmann has reported nepheline-bearing basalt, and Dr. J. W. Evans has lately communicated specimens of foyaite and augite-syenite from Pão de Assucar on the Paraguay, proving that this mass, hitherto reputed to be granitic, represents another eruptive center similar to those studied in eastern Brazil.

The evidence of consanguinity of foyaite and phonolite consists of an intimate association within limited areas at all of the localities mentioned, except Ipanema, where neither type has as yet been found in a condition to be positively identified; of a direct passage to phonolite at the margins of foyaite masses at Caldas; of inclusions of phonolite in foyaite at the same place and conversely of inclusions, evidently formed *in situ* of foyaite in phonolite at Caldas and Tingua. In this connection may be mentioned an inclusion of the type of

foyaite, described by Prof. Rosenbusch and Dr. G. H. Williams from the phonolite massif of the island of Fernando de Noronha, whose eruption is presumed to be of much later date than that of the continental centers above described. Whatever may be the explanation of the assumption of the leucite form, without the substance of that mineral, by these inclusions at Caldas and Tingua, this phenomenon may also be cited as an evidence of consanguinity. Confirmatory evidence is afforded by the intimate association of typical leucite and nepheline rocks in the Caldas massif, and perhaps also by the occurrence in Paraguay.

The evidence of consanguinity of the augite-syenite type with those bearing nepheline is almost equally complete. At Tingua, where there is an apparent lack of this type, a single large fragment was found as an inclusion in foyaite. At Jacupiranga, a direct passage by disappearance of nepheline, from foyaite to one phase of augite-syenite could be traced, while other phases of the same type were found associated with foyaite in the same dyke or boss. Most interesting is the association of this type at Jacupiranga and Ipanema with nepheline rocks more basic than the foyaites and phonolites, such as the jacupirangites and phonolitic nephelinites, in the latter of which it occurs as an inclusion or segregation. In this connection it is interesting to note the tendency, rare among the orthoclase rocks, of this type to present olivine as an accessory element.

Still more interesting, though less conclusive, are the indications of consanguinity of foyaite with a group of plagioclase rocks hardly, if at all, distinguishable from those of entirely different genetic relations. At Cabo Frio the appearance is certainly that of segregations of a plagioclase rock in the midst of foyaite, though farther investigation is desirable. At Jacupiranga the two types not only occur in the same dyke or boss, but nepheline has actually been observed as a rare accessory in the gabbro-like rock. The appearance of plagioclase in the pseudo-leucite crystals of Tingua bears on the same question, as does also the appearance in a large collection of phonolite from Fernando de Noronha of a single specimen of an andesite-like rock, which unfortunately

was not observed in time to be included in the material sent to Dr. G. H. Williams for study. Apparently there is a group of gabbro and diabase-like rocks whose genetic relations are with the nepheline-bearing rocks rather than with the ordinary members of the groups which they so closely resemble.

The peculiar and varied group of basic dyke rocks recently denominated monchiquites by Prof. Rosenbusch, afford evidences of consanguinity by their almost constant association, as apophyses, with the nepheline-bearing eruptive centers to whose immediate vicinity they appear to be limited. If certain decomposed dykes at Caldas and Ipanema are correctly referred, this group occurs at all the Brazilian localities. A single instance of a basic segregration resembling this type has been observed in a dyke of phonolite. The occurrence within the space of a few meters in the Tingua phonolitic tuffs of three small dykes of this type, of which two, standing alone, would be taken as representing tephrite and limburgite is suggestive of another line of consanguinity. Equally suggestive is the occurrence of vosgesite in the vicinity of the Jacupiranga center of eruption.

Finally the evidence of volcanic action in the presence of fragmental eruptives found at all of the five localities in constant association with types ordinarily regarded as plutonic, such as augite-syenite, is exceedingly suggestive.

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SÃO PAULO, BRAZIL, Aug. 1, 1893.